



Acoustics Discipline Overview

*Fundamental Aeronautics Annual Meeting
New Orleans
October 30 - November 1, 2007*

Dr. Edmane Envia, NASA Glenn Research Center
Dr. Russell Thomas, NASA Langley Research Center

As part of the Fundamental Aeronautics Program Annual Review, a summary of the progress made in 2007 in acoustics research under the Subsonic Fixed Wing project is given. The presentation describes highlights from in-house and external activities including partnerships and NRA-funded research with industry and academia. Brief progress reports from all acoustics Phase 1 NRAs are also included as are outlines of the planned activities for 2008 and all Phase 2 NRAs.



Outline of Noise Session

- Acoustics Discipline Overview

Drs. Edmane Envia and Russell Thomas, NASA

- Aircraft Noise Prediction Program (ANOPP) Developments

Mr. Michael Marcolini, NASA

- Acoustic Prediction State of the Art Assessment

Dr. Milo Dahl, NASA

- Chevron Nozzle Large Eddy Simulation Computations

Dr. Ali Uzun, Florida State University

- Airframe Noise Benchmark Problem for Unsteady Computations

Dr. David Lockard, NASA

- Engine Validation of Noise Reduction Technology

Mr. Donald Weir, Honeywell



Acoustics Discipline Overview

Dr. Edmane Envia

Dr. Russell Thomas

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Presentation Outline

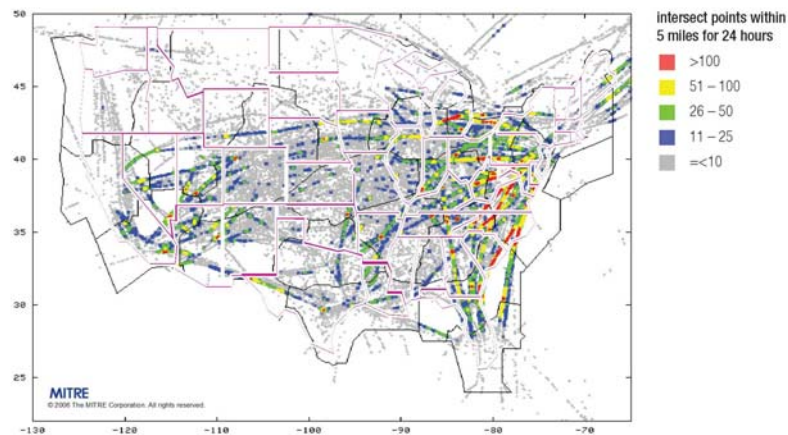
- Discipline Overview
 - Background
 - SFW Project Goals
 - Research Plan
 - Technology Path to Noise Goals
 - Industry Partnerships & Collaborations
 - Phase 2 NRA Plans
- Review of FY07 Accomplishments
 - Assessment Task
 - Phase 1 NRA Progress Reports
- Highlights of FY08 Plans
 - NRA Phase 2
 - Partnerships
 - Highlights of In-House Deliverables
- Summary



Motivation

- The Joint Planning and Development Office (JPDO) is designing the Next Generation Air Transportation System (NextGen) with the potential for a 3x increase in air traffic capacity by 2025.
- Reducing aircraft noise is critical for enabling this anticipated growth. Recent JPDO studies indicate that, without a significant influx of new noise reduction technology into the fleet, the number of people exposed to objectionable noise levels (>65 DNL) will grow significantly.

Density of High Altitude Air Traffic (Current)

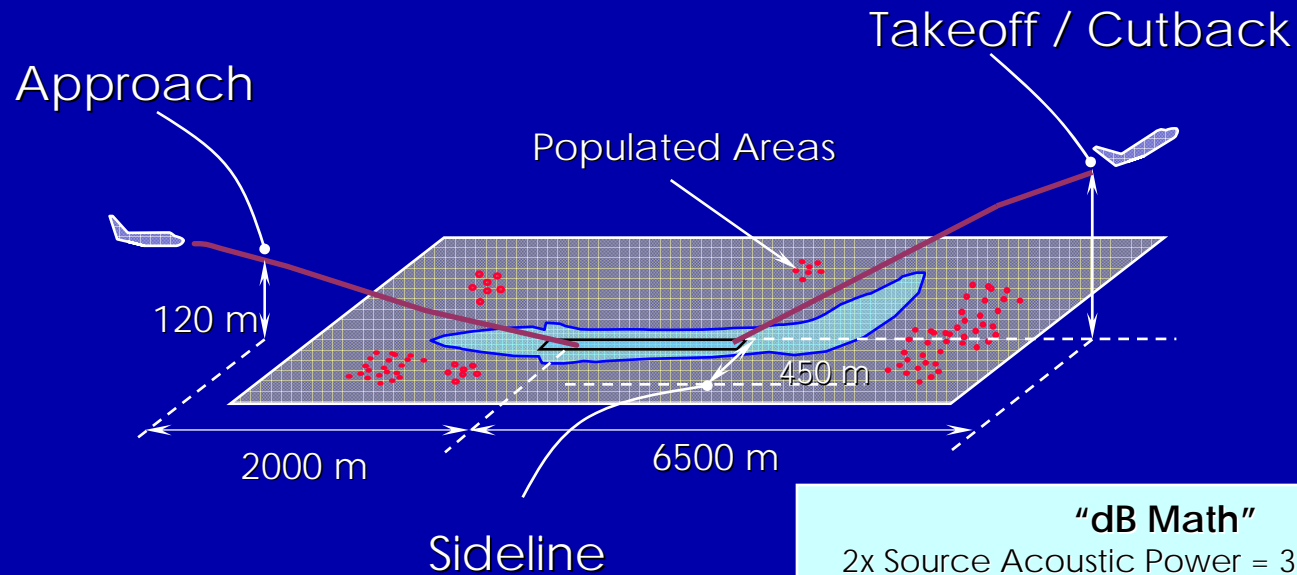


**Density of High Altitude Air Traffic
(~2025 at 3X Traffic Levels)**



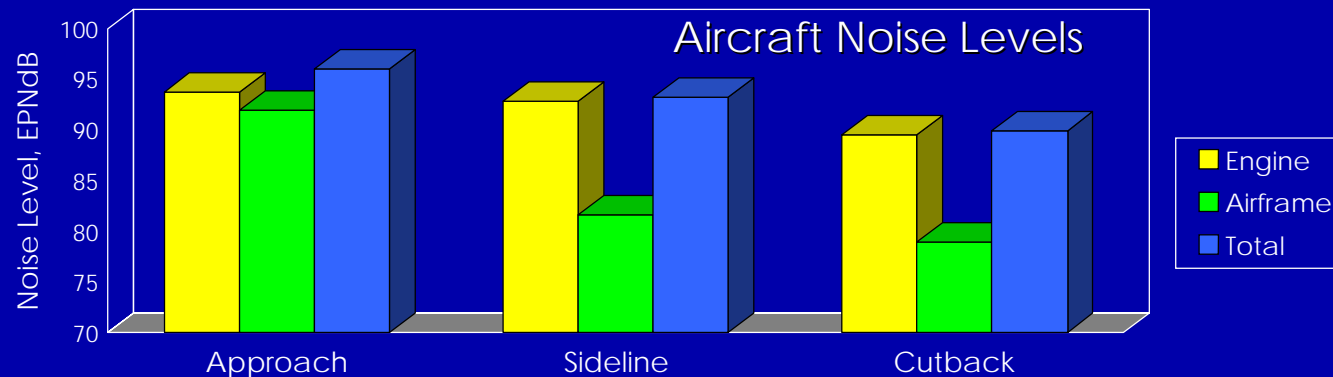


Aircraft Noise Metrics



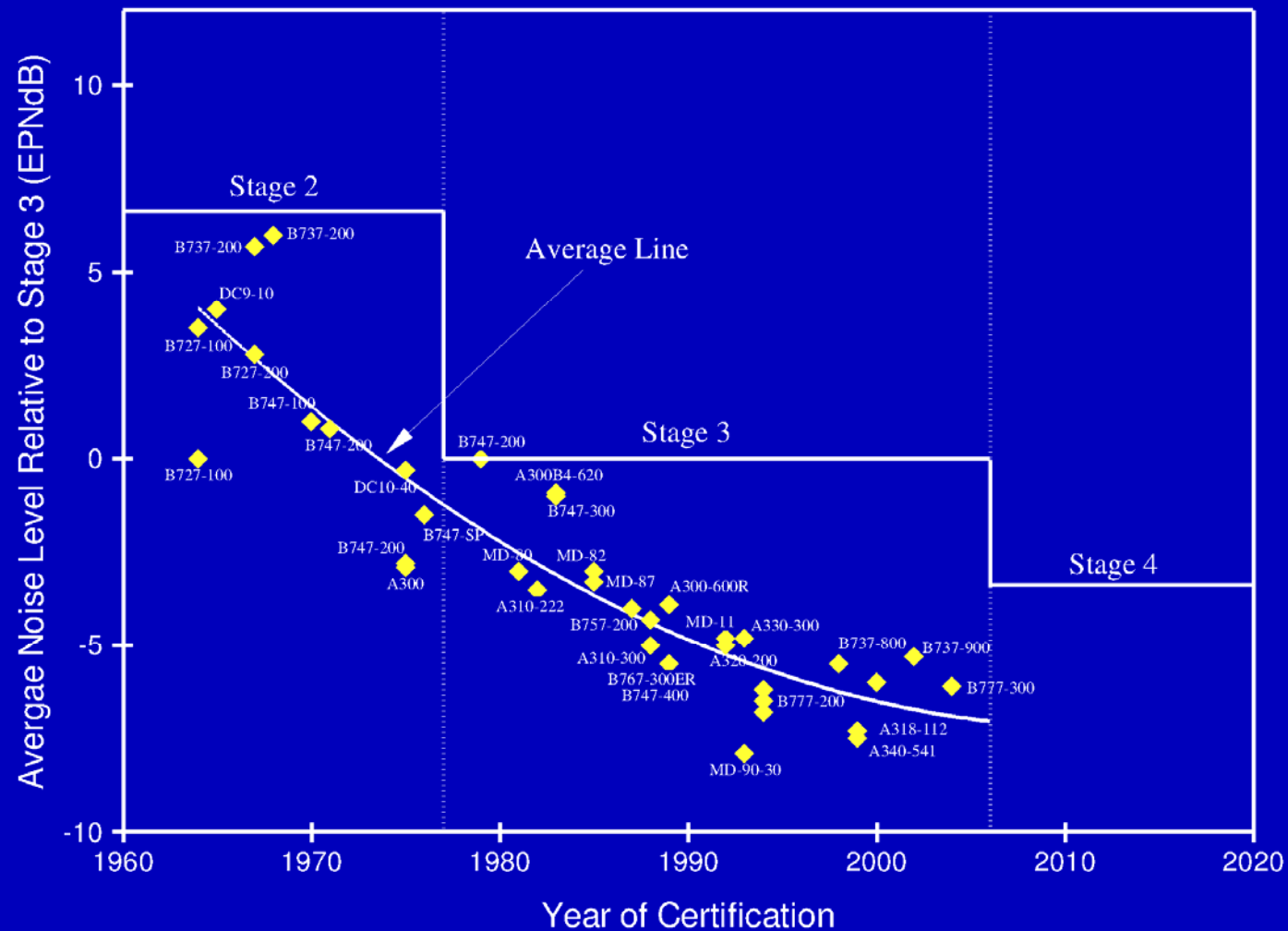
"dB Math"

2x Source Acoustic Power = 3 dB Increase
10x Source Acoustic Power = 10 dB Increase



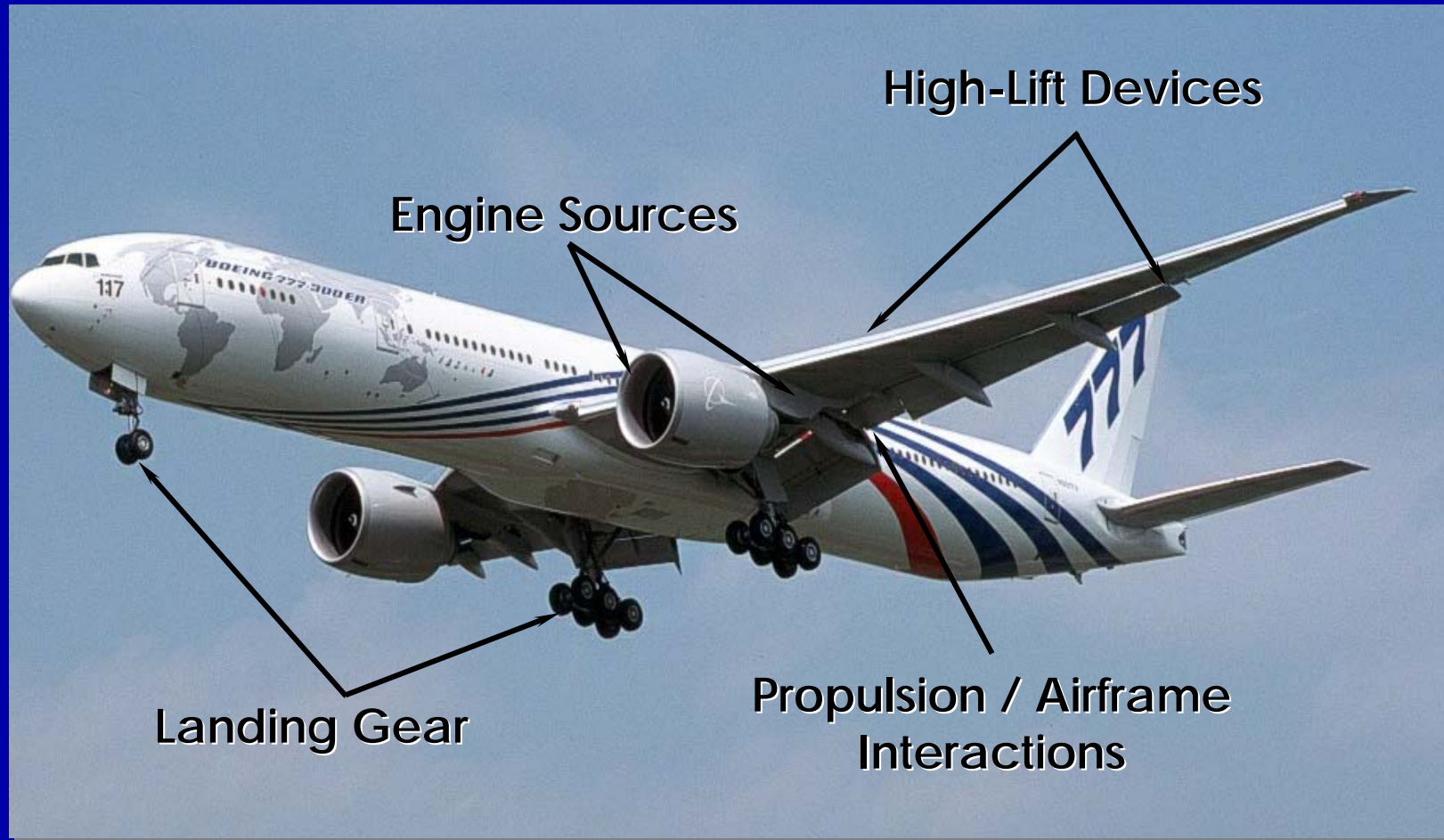


Aircraft Noise Trend





The Challenge



Aircraft noise is a complex amalgam of sources, interactions, transmission, and propagation.



Subsonic Fixed Wing Project Goals

Corners of the Trade Space	<i>N</i> +1 Generation Conventional Tube w/ Wing (2012-2015)	<i>N</i> +2 Generation Unconventional Hybrid Wing Body (2018-2020)
Noise (cumulative below Stage 3)	-42 dB	-52 dB
Emissions (LTO NO_x) (below CAEP/2)	-70%	-80%
Performance: Aircraft Fuel Burn (relative to 737/CFM56)	-33%	-50%*
Performance: Field Length (relative to 737/CFM56)	-33%	-50%

N+1 Generation



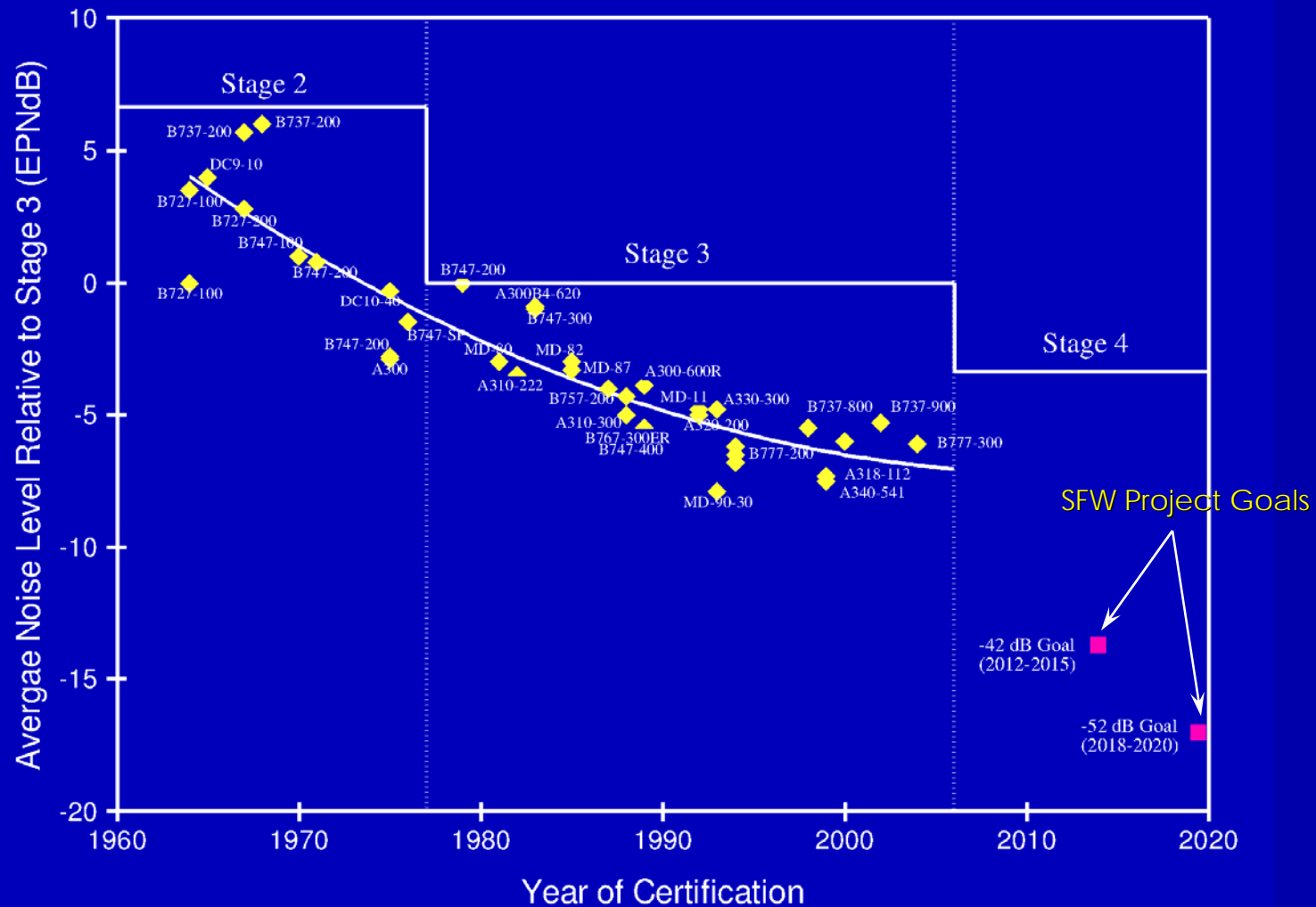
N+2 Generation



* Fuel burn for *N*+2 being validated.



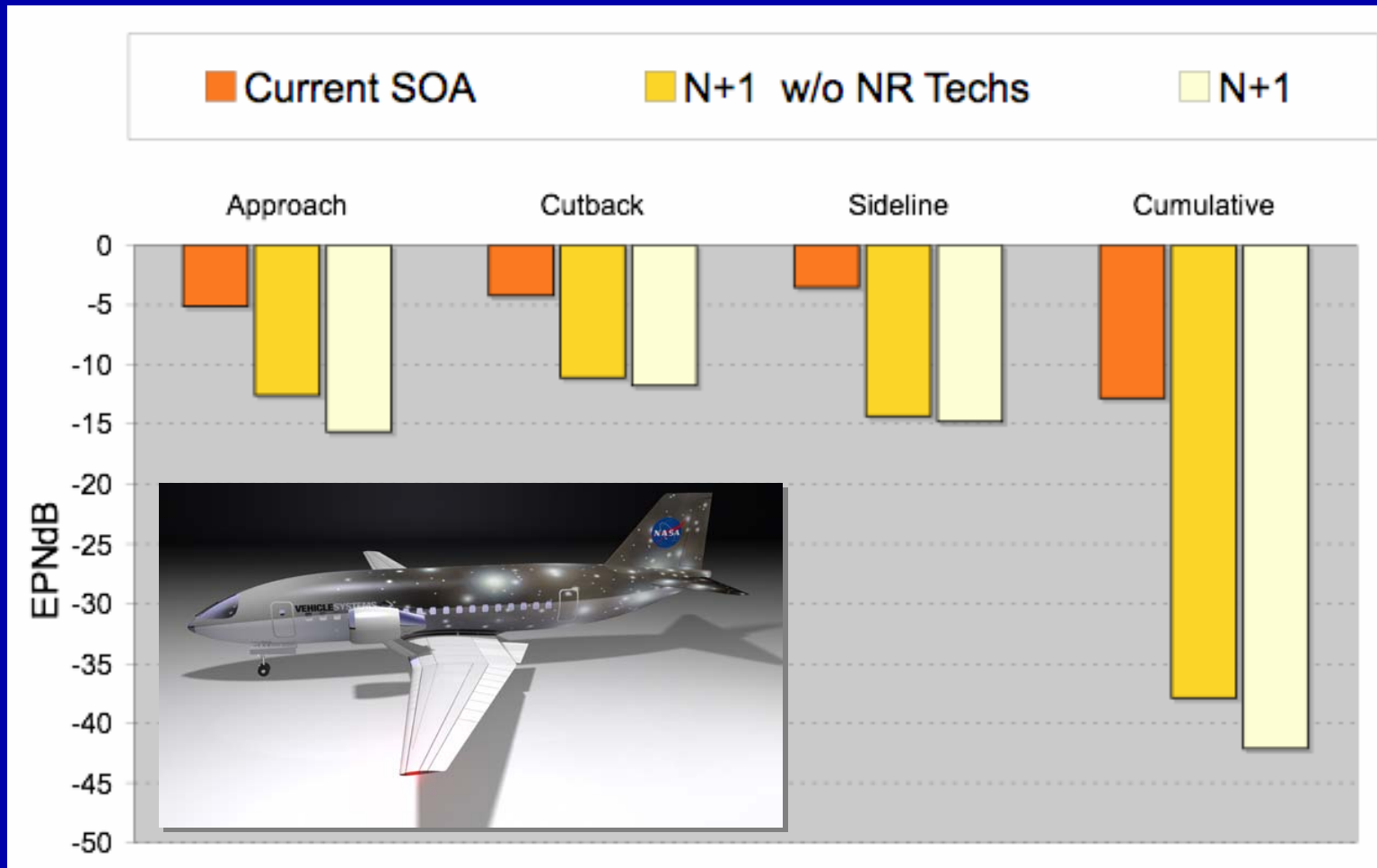
Step Change in Noise Trend

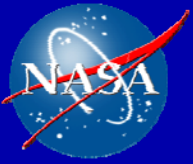




$N+1$ Aircraft Noise Margins

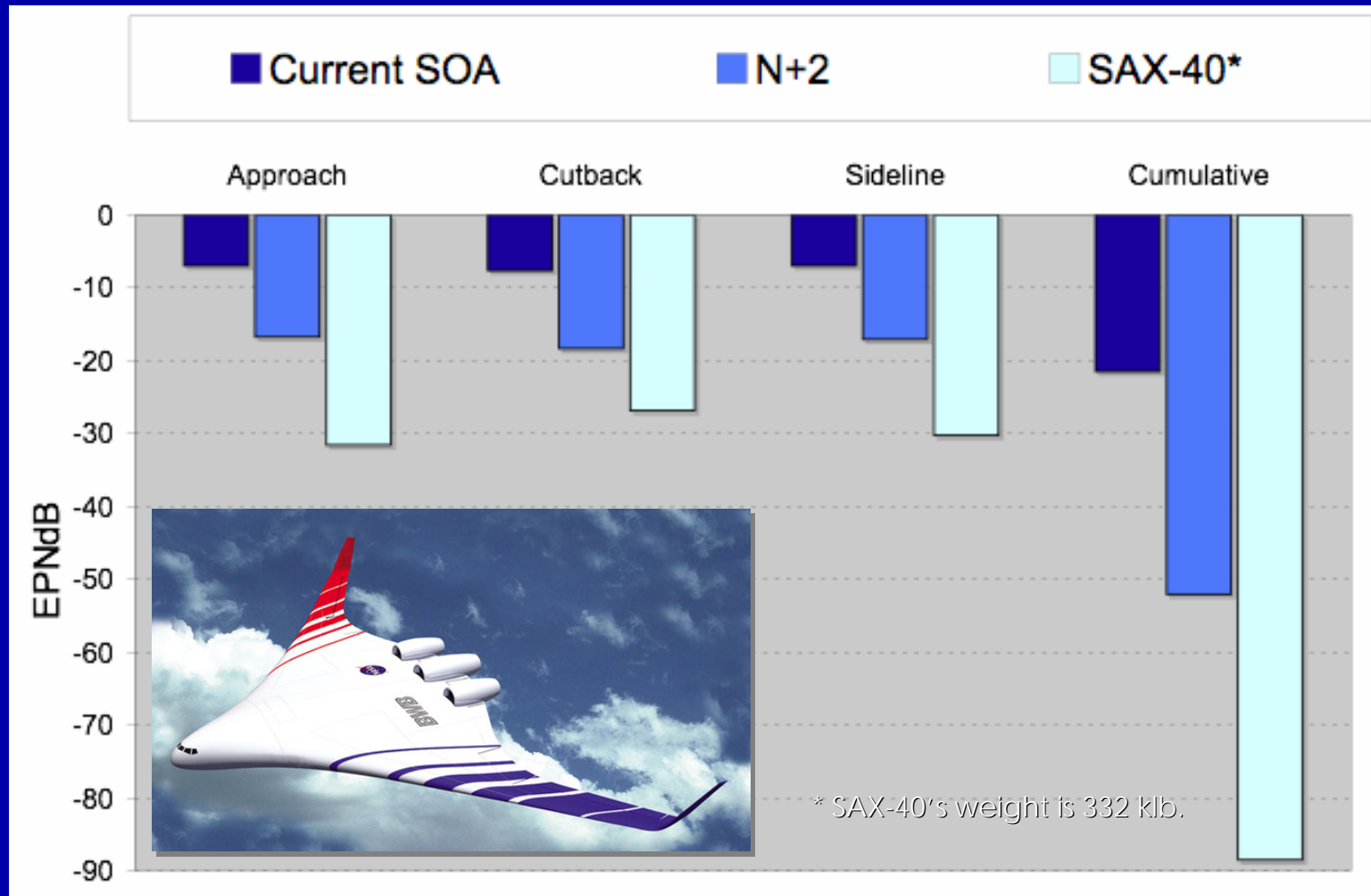
(All numbers relative to Stage 3 certification levels)





N+2 Aircraft Noise Margins

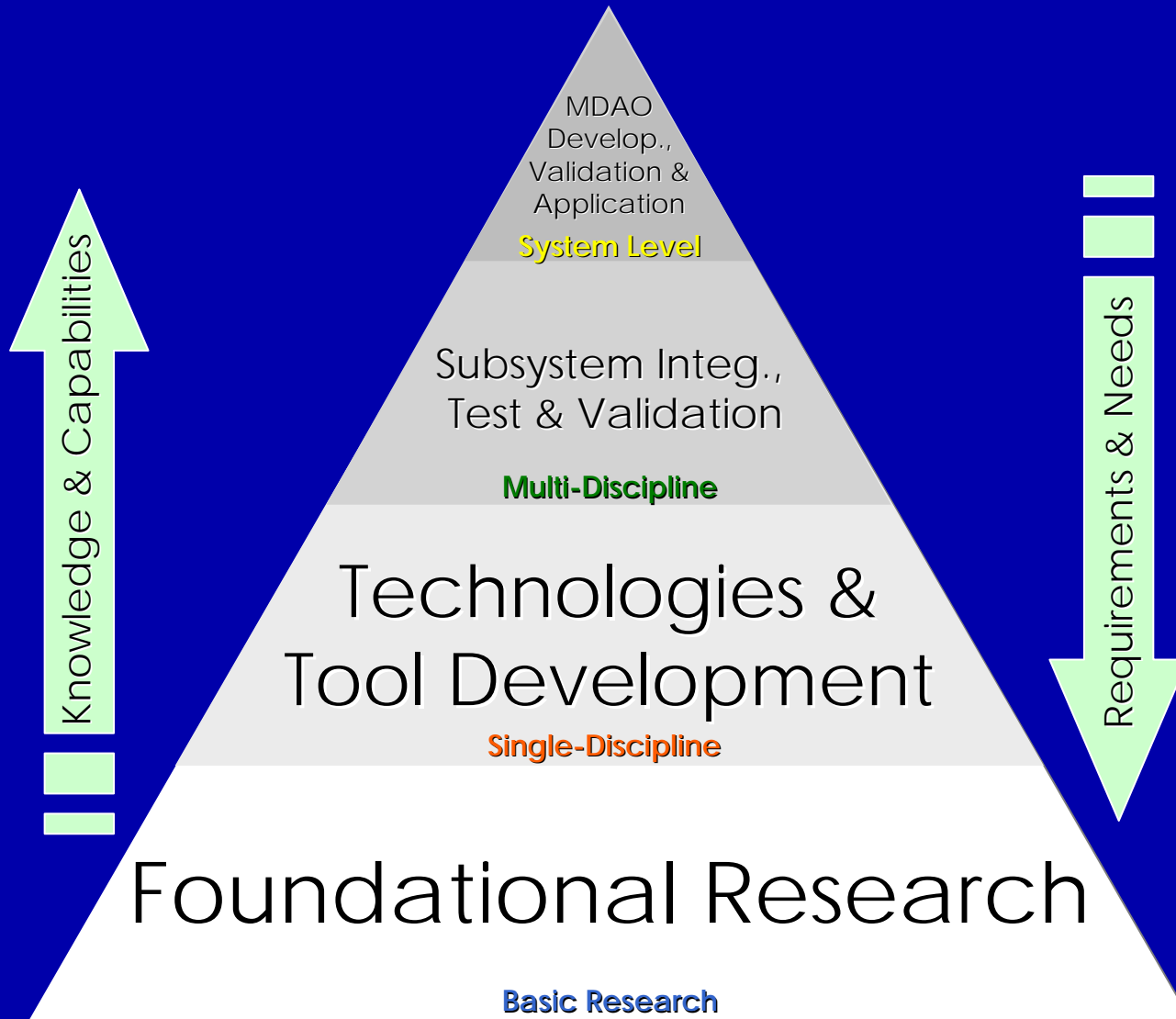
(All numbers relative to Stage 3 certification levels)





Research Approach

NASA In-House Research



NRA Funded Research Industry & OGA Cooperative Agreements



$N+1$ Technology Path

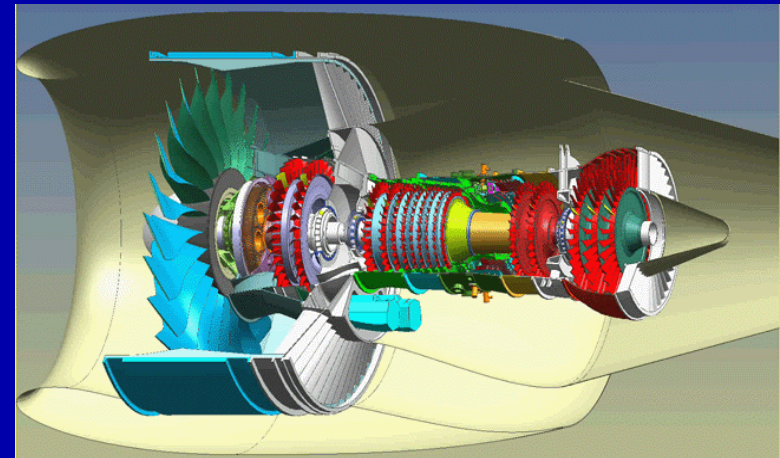


Airframe Noise Reduction Technologies:

- Slat Cove Filler & Continuous Mold Line (CML)
(for high-lift systems noise reduction)
- Toboggan Fairing
(for landing gear noise reduction)

Engine Noise Reduction Technologies:

- Ultra High Bypass (UHB) Cycle
(e.g., geared turbofan)
- Soft Vane Stator
- Over-The-Rotor Treatment
(all for fan noise reduction)





Pratt & Whitney Partnership

- 9'x15' Acoustic Wind Tunnel Fan Noise Reduction Validation Test:
 - UHB Cycle Noise Benefits (*Test Completed in November '06 - Cycle Benefits Validated*)
 - Over-The-Rotor & Soft Vane Fan NR Tech. Validation Test (*Scheduled or September '08*)
- 11' Transonic Wind Tunnel Test:
 - Potential Aerodynamic Integration Study (*Scheduled for April '08*)
- Geared Turbofan (GTF) Static Engine Test
 - Potential for Sub-Scale/Full-Scale Fan Noise Data Comparison (*Scheduled for Nov. '07*)



P&W GTF Model Scale Fan
in 9'x15' WT



Fan Noise Reduction Technology
Testbed in 9'x15' WT



Gulfstream Partnership



FY07 Flight Test at
Wallops Island Flight Facility

- Airframe Noise Source Investigation and Mitigation Study:
 - Landing Gear Noise
 - Flap Side Edge Noise

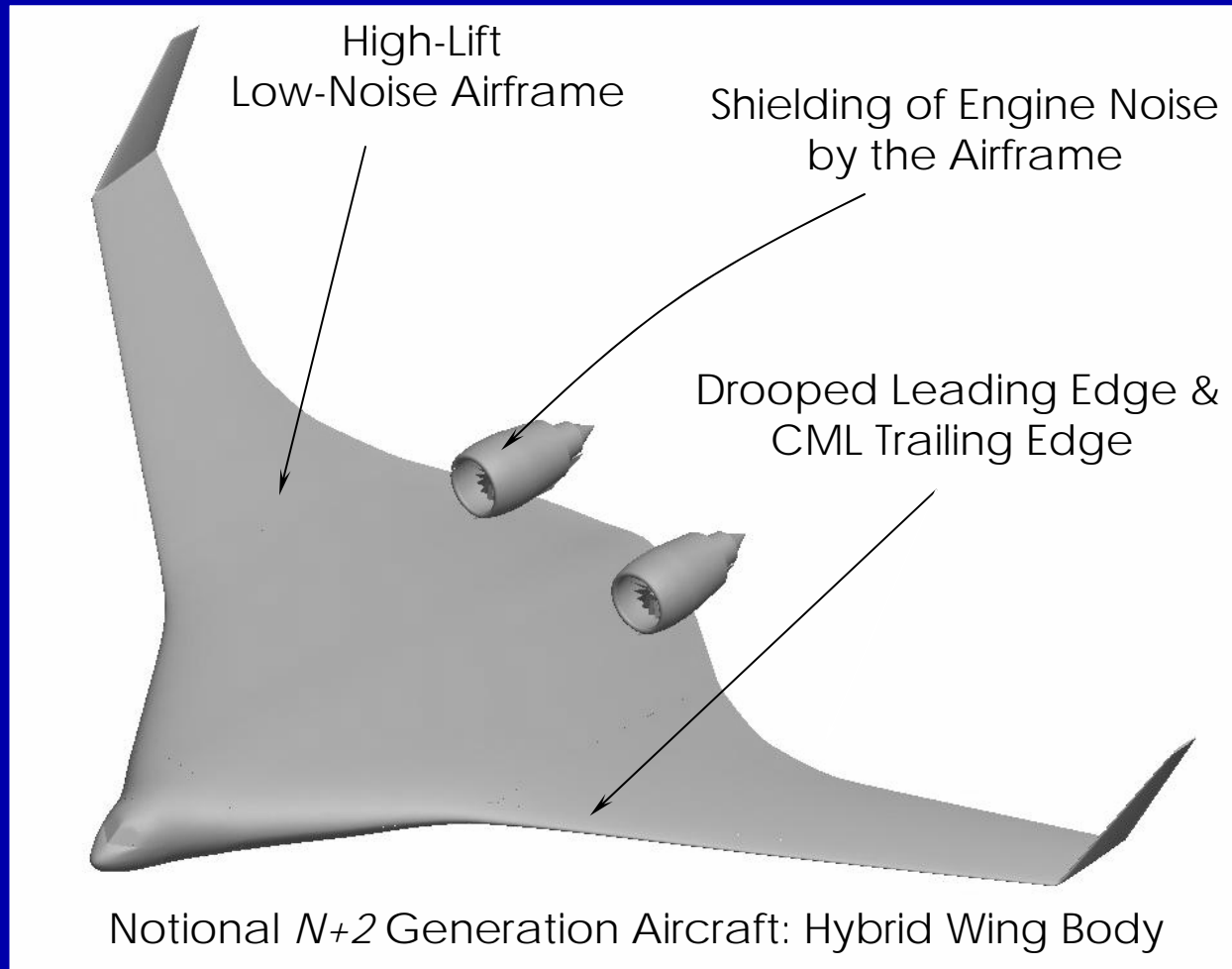
- Multi-Year, Comprehensive Project:
 - Component Flow & Noise Testing
 - Noise Prediction
 - Flight Testing



Nose Gear Test in BART



$N+2$ Technology Path Hybrid Wing Body (HWB)





Boeing/MIT/UCI Round 2 NRA (1/2)

(Acoustics, Aerodynamics, and SADO Disciplines)

PI: Mr. Ronald Kawai, Boeing Phantom Works
Sub: Profs. Spakovszky (MIT) & Papamoschou (UCI)
NASA TM: Dr. Florence Hutcheson & Mr. Gregory Gatlin

Start Date: October 1, 2007
Year 1: \$1.6M
Year 2: \$1.5M
Year 3: \$1.5M

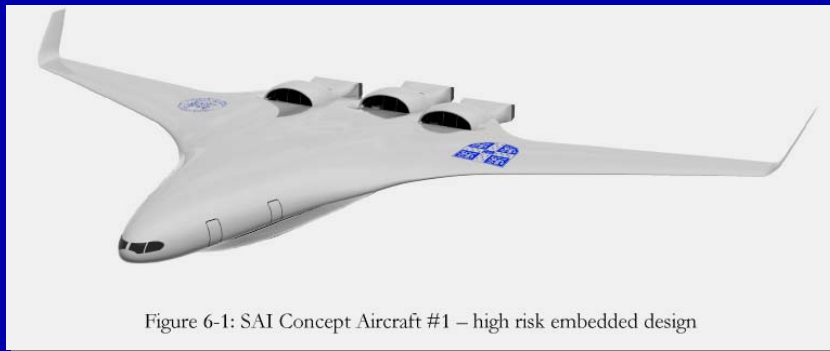


Figure 6-1: SAI Concept Aircraft #1 – high risk embedded design



Figure 6-2: SAI Concept Aircraft #2 – reduced risk podded design

Cambridge-MIT SAX-40 Conceptual Designs for 2025

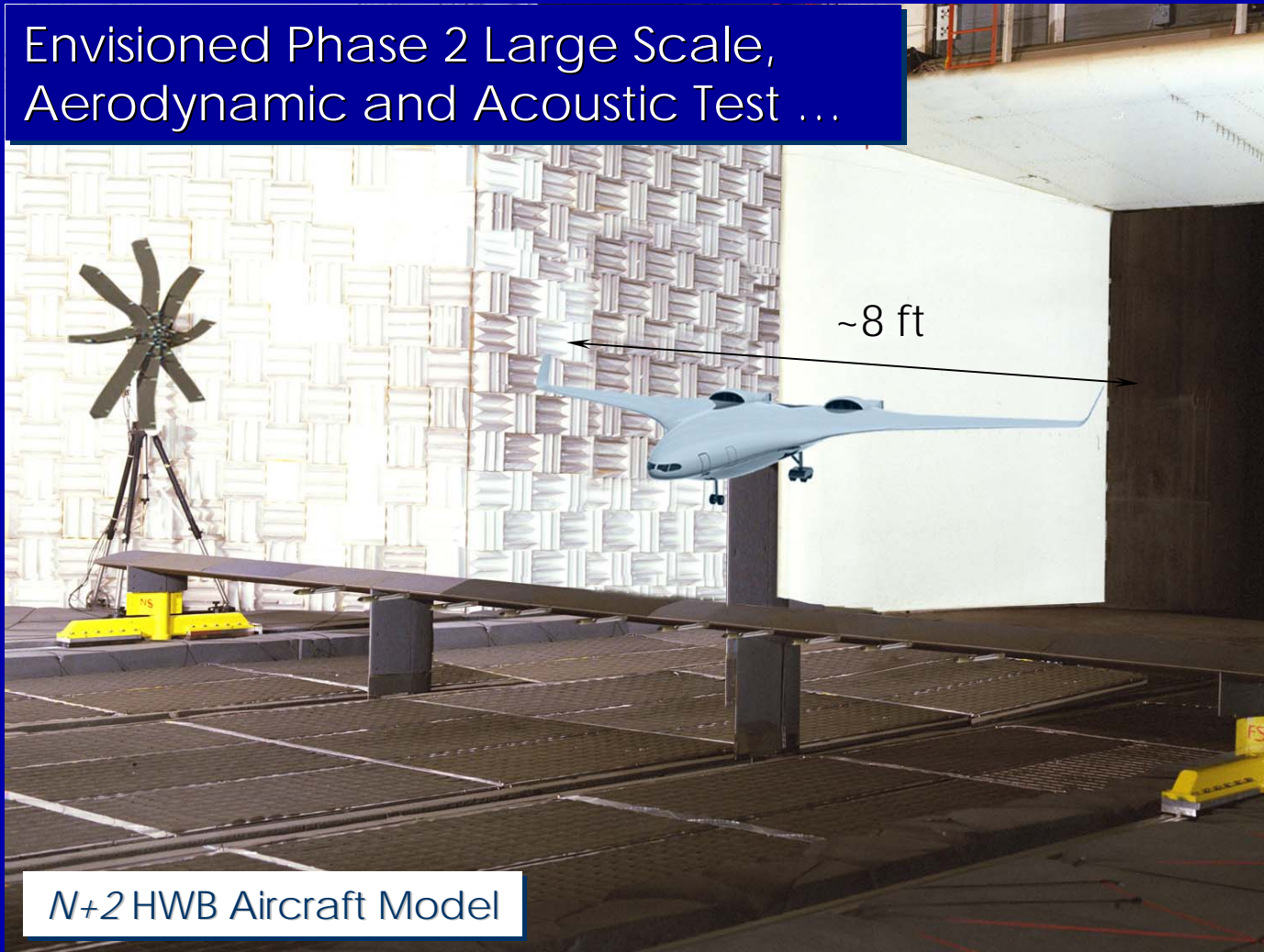
- Boeing Phantom Works NRA:
 - Start with both SAX-40 Concepts (Embedded and Podded Engines)
 - Mature Design for both Concepts; NASA/MIT/UCI Team to Carry Out Noise Assessment
 - Technology and Validation Wind Tunnel Selection for Phase 2



Boeing/MIT/UCI Round 2 NRA (2/2)

(Acoustics, Aerodynamics, and SADO Disciplines)

Envisioned Phase 2 Large Scale,
Aerodynamic and Acoustic Test ...



N+2 HWB Aircraft Model



Integrated Modeling and Verification of Hybrid Wing-Body, Low Noise ESTOL Aircraft

PI: Prof. David Marshall, Cal Poly Corporation, San Luis Obispo, California

NASA TM: Mr. Craig Hange & Dr. Joe Posey

Start Date: October 1, 2007

Year 1: \$892K; Year 2: \$1,593K; Year 3: \$1,340K

Objective:

- Develop and validate predictive capabilities for the design and performance of Cruise Efficient, Short Take-Off and Landing (CESTOL) subsonic aircraft
- Validate predictive capabilities for an estimate of CESTOL aircraft noise during takeoff and landing

Approach:

- Determine the low-speed aerodynamic characteristics up to and beyond maximum lift via a combination of computational and experimental efforts in order to obtain a more complete picture of the flow physics
- Determine the acoustic characteristics of a low-noise hybrid wing-body system via experimental efforts and noise signature modeling to analyze not just the noise generated by the vehicle, but also to analyze the noise footprint around the airport during takeoff and landing
- Select and refine one CESTOL concept and then complete a preliminary design of a large scale wind tunnel model and test

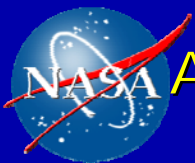
Key Accomplishments to Date:

- Evaluations of candidate conceptual designs and powered-lift systems for landing and take-off performance, mission performance, and overall size, weight, and payload



Upcoming Year 1 milestone:

- Improved modeling of the complex flow field generated by the powered-lift system by improving computational modeling techniques and extending the range of available experimental data that characterizes the flow field



A Noise Assessment Methodology for Highly Integrated Propulsion Systems with Inlet Flow Distortion

PI: Prof. Zoltan Spakovszky, Massachusetts Institute of Technology

NASA TM: Dr. Russ Thomas

Objective:

- Develop a high fidelity (RANS and unsteady RANS), coupled aerodynamic and aero-acoustic computational method for fan noise propagation and radiation in non-uniform flow (e.g. S-inlets)
- Develop a reduced order model to incorporate in ANOPP

Approach:

- Zonal approach: 3D steady RANS of fan stage coupled with body-force method for blade response, unsteady 3D Euler calculation of propagation through inlet and external radiation
- Key challenge is passing information from each zone/method

Start Date: June 1, 2007

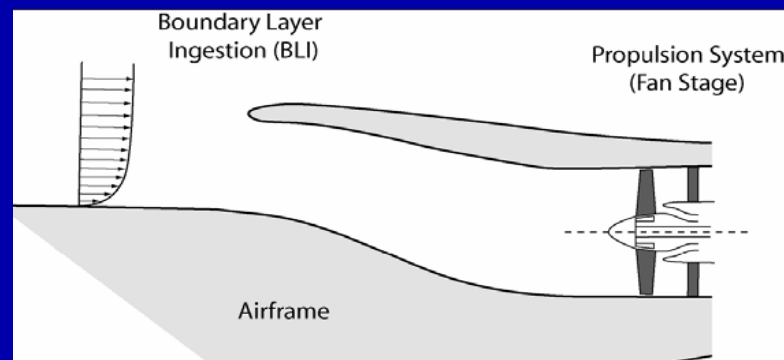
Year 1: \$190K; Year 2: \$154K; Year 3: \$159K

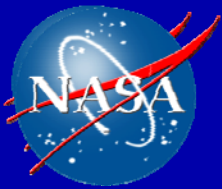
Key Accomplishments to Date:

- Acquired Source Diagnostic Test (SDT) Fan geometry and data from NASA to be used as validation case for method before progressing to S-inlet geometry

Upcoming Year 1 milestone:

- Assemble computation process and compute at least one subsonic and supersonic case each from SDT data set and validate against flow data





External Aircraft Noise Control Using Dielectric Barrier Discharge Actuators: Benchmark Experiments and LES Simulations

PI: Prof. Flint Thomas, University of Notre Dame

NASA TM: Mr. Clifton Horne & Mr. William Humphreys

Start Date: August 1, 2007

Year 1: \$164K; Year 2: \$173K; Year 3: \$184K

Objective:

- Perform benchmark flow control experiments and corresponding LES simulations that demonstrate the ability of DBD plasma actuators to achieve on-demand active airframe noise control without incurring significant aerodynamic penalty

Approach:

- Experiments and simulations will focus on active control in three generic component configurations : (1) landing gear, (2) partial span flap side-edge, (3) leading edge flap
- Current focus is on "plasma fairing" for landing gear noise reduction

Key Accomplishments to Date:

- Demonstrated the plasma fairing concept to reduce bluff body wake turbulence and radiated noise at $Re_D = O(10^3 - 10^5)$



Upcoming Year 1 milestones:

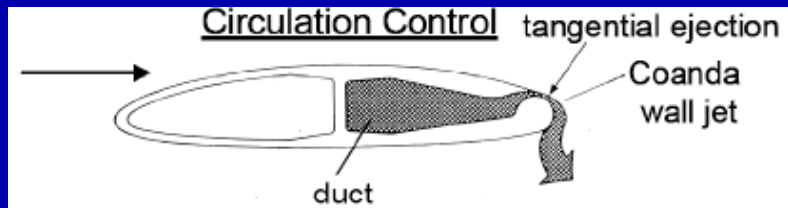
- Achieve an experimentally validated LES computational capability for predicting plasma-based flow control of airframe noise
- Develop DBD actuators with sufficient authority for operation at velocities typical of commercial transport landing and take-off



Unsteady Circulation Control for High-Performance Low-Noise Aircraft

PI: Prof. Lou Cattafesta, University of Florida

NASA TM: Drs. John Lin & Mehdi Khorrami



Start Date: August 21, 2007

Year 1: \$265K; Year 2: \$584K; Year 3: \$556K

Approach:

- Investigated aerodynamic performance and aeroacoustic characteristics of unsteady CC airfoils in UF anechoic flow facility using a combination of fluid dynamic measurements and several advanced microphone array techniques
- Extend adaptive flow control schemes to optimize the combined aerodynamic and aeroacoustic performance of the system
- Develop and validate an existing flow solver and noise prediction tool for unsteady CC airfoils

Upcoming Year 1 milestone:

- Acquire and compare aerodynamics data for unsteady and steady CC airfoil at identical flow conditions and lift coefficient
- Assess CFL3D coupled w/ FW-H acoustic code
- Develop/evaluate advanced beamforming techniques for extracting/localizing noise sources

Objective:

- Conduct detailed fluid dynamic and aeroacoustic experiments to understand the underlying physics of the flow behavior and noise generation mechanisms
- Provide high quality benchmark fluid dynamic and aeroacoustic data for parallel prediction tool development
- Conduct simulation and analysis of the unsteady flow field and noise source acoustic characteristics

Key Accomplishments to Date:

- Initiate CFL3D RANS and acoustics computations of Circulation Control airfoil
- Initiate pre-test preparation for unsteady Circulation Control airfoil



Fast Scattering Code Development

PI: Dr. Mark Dunn

NASA TM: Dr. Douglas Nark

Start Date: February 1, 2007

Year 1: \$290K; Year 2: \$300K

Objective:

- Predict the scattered acoustic field produced by the interaction of known, time harmonic, incident sound with arbitrary 3-D aerostructures in the presence of a potential background flow using desktop workstation technology

Approach:

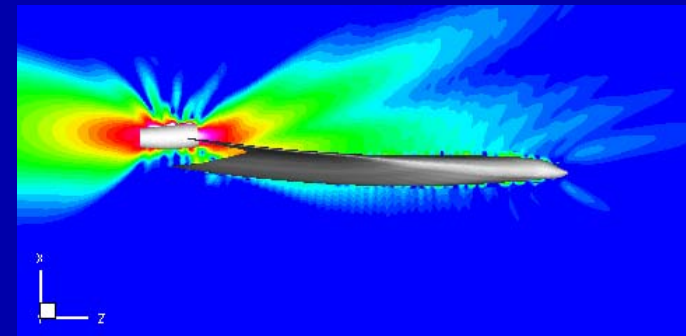
- Solves an exterior Helmholtz BVP using the equivalent source method (ESM) – ESM requires 1/9 memory and 1/27 computational time than other boundary approaches such as boundary element or boundary integral methods
- Single and multiple level fast multipole methods (FMM)
- Advanced sparse linear algebra strategies
- Parallelization techniques

Upcoming Year 1 waypoints/milestone:

- Nacelle alone predictions for $f = 3 \times \text{BPF}$
- Tube and wing configuration predictions for $f = 1 \times \text{BPF}$
- Deliver FSC v3.0 featuring SLFMM and iterative matrix solver

Key Accomplishments to Date:

- Full scale tube and wing configuration
 - $f = 0.4 \times \text{BPF}$, $M = 0.0$, stationary monopoles at nacelle centers
 - CPU time improvement: ESM/FMM = 4.18 (scattered field)
- Full scale hybrid wing configuration
 - $f = 180 \text{ Hz}$, $M = 0.0$, spinning monopole ($m = 0$) at nacelle center
 - CPU time improvement: ESM/FMM = 4.31 (scattered field)





Review of FY07 Accomplishments

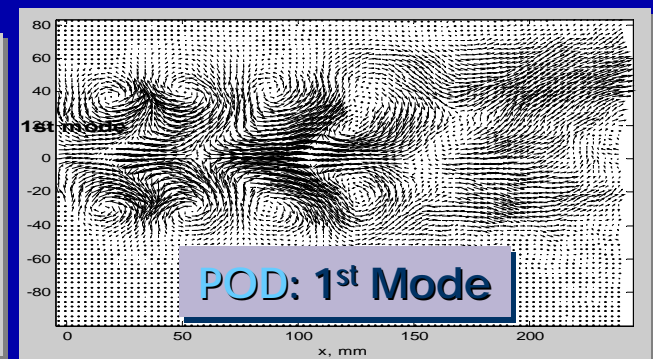
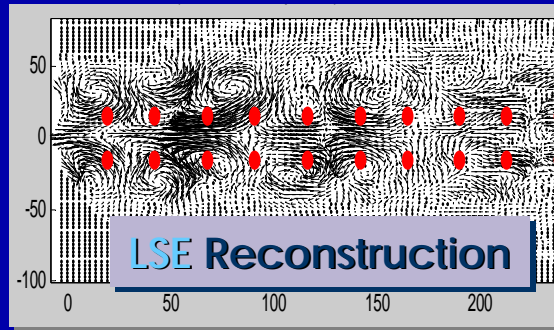
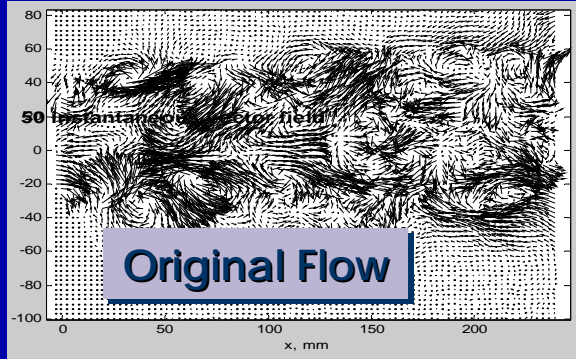
- Assessment Task
 - Establishing the Current State of the Art in Aircraft Noise Prediction
- ANOPP Level 25 Release
- Phase 1 NRA Progress Topics and Reports
 - High Fidelity Simulation of Fan Noise Propagation in S-inlets (linked to $N+2$)
 - Acoustic Scattering Code Development (linked to $N+2$)
 - Simultaneous Measurements in Jet Flows
 - Combustion Noise Modeling
 - Phased Array Methods for Extended Sources
 - High Fidelity Simulations of Airframe Noise
 - High Fidelity Simulations of Chevron Nozzles
 - Reduced Order Model for Airframe Noise



POD and LSE Analysis of Simultaneous Measurements of Velocity, Near Field Pressure, and Temperature Fluctuations in Coaxial High Subsonic Jet Flow

PI: Prof. Ephraim Gutmark, Univ. of Cincinnati, Co-PI: Prof. Ron Hanson, Stanford
NASA TM: Dr. James Bridges

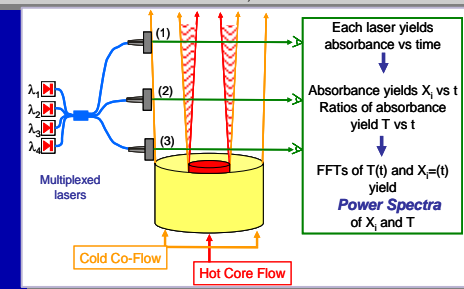
Description: Simultaneous measurements of unsteady velocity, pressure and temperature using a new laser based temperature fluctuations sensor. Proper Orthogonal Decomposition (POD) and Linear Stochastic Estimation (LSE) are used to study the jet flow structures and the physics of sound generation.



Status:

UC: POD and LSE software was developed and tested using data from a high-speed subsonic jet. Analysis was performed using simultaneous planar velocity data from 2-D Particle Image Velocimetry (PIV) and near-field pressure fluctuations captured by an array of near field microphones. Samples of resulting analysis are shown here.

Stanford: Tested the temperature probe at frequencies of up to 10kHz in supersonic flow and developed algorithm to identified physical properties of hot and cold flow regimes.



Temperature Sensor





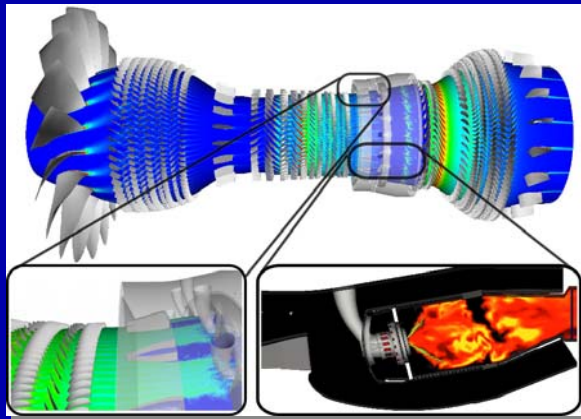
Detailed Modeling of Combustion Noise Using a Combined Large-Eddy Simulation/ Computational Aeroacoustics Model

PI: Prof. Heinz Pitsch, Stanford University
NASA TM: Dr. Lennart Hultgren

Start Date: January 16, 2007

Year 1: \$309K; Year 2: \$367K; Year 3: \$374K

Year 4: \$384K; Year 5: \$395K



Objective:

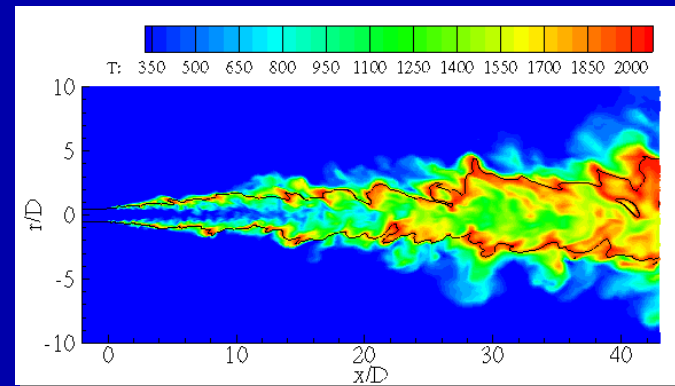
- Develop high-fidelity combustion-noise prediction capability for aeroengines
- Develop reduced-order transmission models

Approach:

- Use existing state-of-the-art nonpremixed combustion models
- Simplified through realistic geometries
- Noise generated by integrated combustor/turbine

Key Accomplishments to Date:

- LES/CAA prediction of noise from open flame
- Implementation of compressible solver in NGA code
- Improved acoustic analogy (Goldstein) in CAA code



Upcoming Year 1 milestone:

- CLES/CAA prediction of acoustic power spectra for dump combustor; 50% reduction of discrepancy between existing predictions and experiments



Improved Phased Array Techniques to Account for Extended Sources of Fan and Jet Noise

PI: Dr. Robert Dougherty, Optinav

NASA TM: Dr. Daniel Sutliff

Start Date: February 5, 2007

Year 1: \$175K; Year 2: \$164K; Year 3: \$140K

Objective:

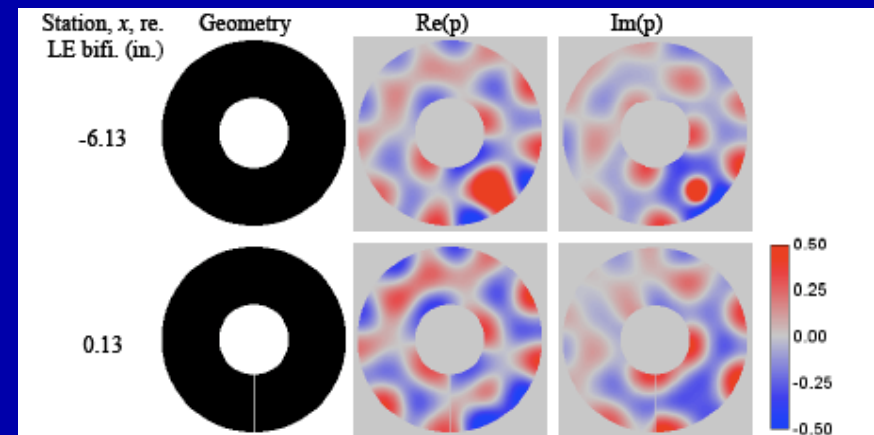
- Develop a non-intrusive in-duct system for source characterization of fan broadband noise
- Develop a phased array for characterization of distributed jet noise

Approach:

- Improve conventional beam forming to account for the physics of moving sources whether due to in-duct rotating sources or from spatially correlated moving sources in a jet
- Develop an array of vector sensors (acoustic pressure and velocity at a point)

Key Accomplishments to Date:

- Computed in-duct steering vectors to guide source detection



Upcoming Year 1 Milestone:

- Plan for ANCF/SHAJR test at GRC



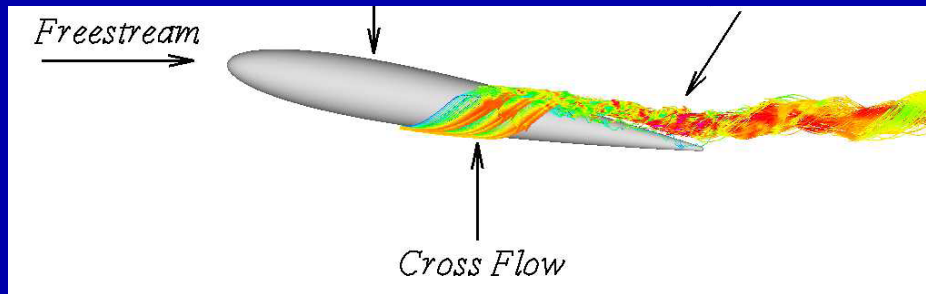
High-Fidelity Numerical Simulations in Airframe Aeroacoustics

PI: Prof. Yousuff Hussaini, Florida State University

NASA TM: Dr. David Lockard

Start Date: January 16, 2007

Year 1: \$113K; Year 2: \$116K; Year 3: \$119K



Objective:

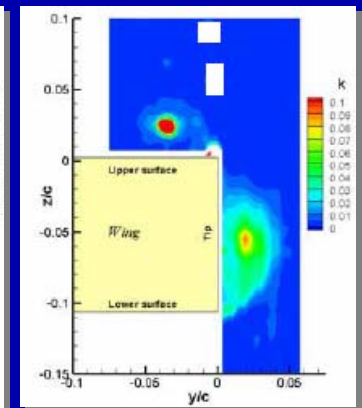
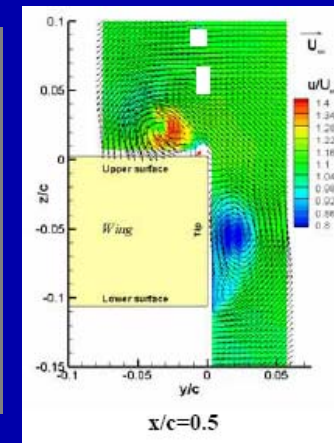
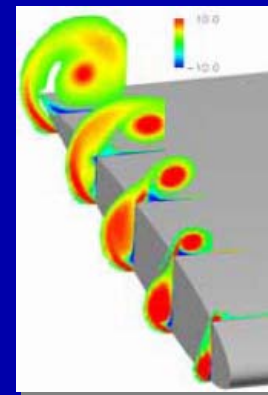
- Develop a state-of-the-art LES/hybrid RANS code
- Simulate tip vortex formation around various flap tip designs
- Investigate jet-flap interaction

Approach:

- Overset, multiblock grids, optimized 4th-order compact differencing, implicit time-stepping, massively parallel, monotonically integrated LES & hybrid URANS/LES
- Key challenge is to sufficiently instigate and resolve unsteadiness in high Re flows to obtain proper boundary layer & shear layer growth and statistical properties

Key Accomplishments to Date:

- Acquired wing tip geometry and data to be used as validation case for method. Performed initial simulations and investigated techniques to introduce unsteady disturbances



Upcoming Year 1 Milestone:

- Complete computation process for a wing tip with a flat edge and validate against flow data



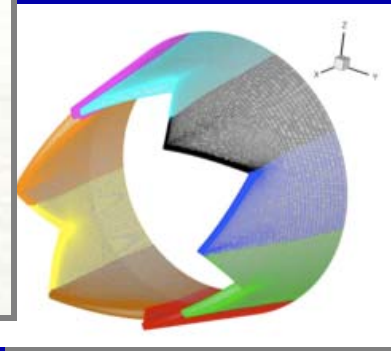
High-Fidelity Numerical Simulations in Jet Aeroacoustics with Application to Chevron Nozzles

PI: Prof. Yousuff Hussaini, Co-PI: Dr. Ali Uzun Florida State University

NASA TM: Dr. Nicholas Georgiadis

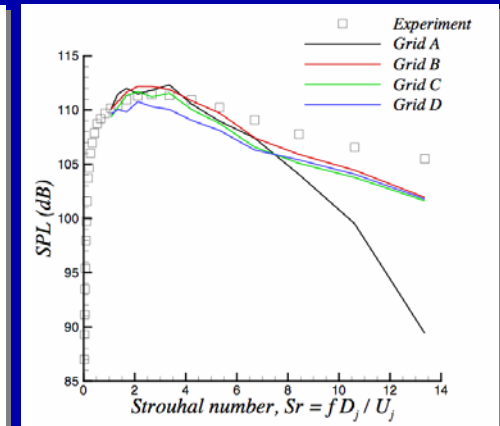
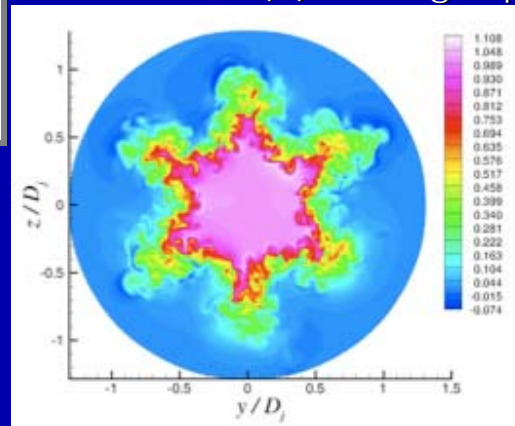
Start Date: Jan. 16, 2007

Year 1: \$116K; Year 2: \$119K; Year 3: 122K



Key Accomplishments to Date:

- Effects of grid density examined (see below) for (A) 50 M, (B) 100 M, (C) 150 M, and (D) 190 M grid points



Objective:

- Develop and utilize state-of-the-art LES method for reference chevron nozzle flow using high-order numerical scheme and as dense grid as possible in jet near-field region

Approach:

- LES Method: 4th order prefactored compact scheme, 4th order Runge-Kutta time integration
- Recycling method used for nozzle internal boundary layers
- Very dense grid in jet near-field region ($x/D=4$) in order to calculate noise source region
- Jet $Re/D = 1.4M$, LES run at 100,000

Upcoming Year 1 milestone:

- Examine SMC001, SMC005, and SMC006 nozzle geometries to examine effect of chevron penetration
- Even more dense grid (1 billion) points may be examined, although not required in proposal. These results would give even better information on LES resolution effects on accuracy of noise spectrum results



Development of the Next Generation of Airframe Noise Prediction Tools

PI: Dr. Yueping Guo, The Boeing Company

NASA TM: Ms. Casey Burley

Revised Start Date: February 5, 2008

Year 1: \$108K; Year 2: \$131K

Objective:

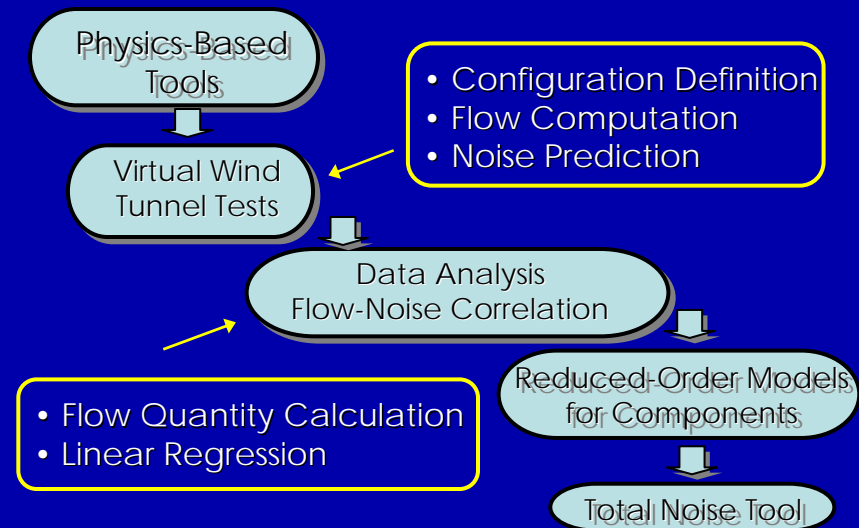
- Develop high fidelity methods for aircraft flap, slat and trailing edge noise that are more physics-based, fast, accurate for both conventional, non-conventional configurations and noise reduction concepts
- Utilize high fidelity CFD results to derive reduced order models for use in aircraft system noise framework (ANOPP-II)

Approach:

- Develop virtual wind tunnel testing capability utilizing prediction methods developed and validated in NASA QAT as a basis to generate databases from which flow-noise correlations may be derived
- Key challenge is ensuring that the key mechanisms responsible for the noise generation are captured within the generated database for a wide range of realistic configurations and flow conditions

Key Accomplishments to Date:

- Delayed start due to technical issues in 'efficient' CFD tool development



Upcoming Year 1 milestone:

- Develop and validate design-oriented prediction tool by integrating codes developed for Reynolds stress calculation, source correlation modeling and Greens function computation



Highlights of FY08 Plans

- NRA Round 2 Awards Initiated
 - Specifically integrating $N+2$ NRAs with in-house research
- Pursue Partnership Plans
 - Pratt and Whitney UHB Engine
 - Gulfstream
- In-House Research Deliverables (Representative)
 - Proof-of-concept demonstration of embedded, self-contained, wireless sensor concept for unsteady surface pressure measurements
 - Document semi-empirical model for one class of foam liners
 - Linearized Euler propagation code with 3D and mean flow effects
 - Curvature effects on noise reduction from CDTR tests documented
 - Adapted, unstructured flow solution method for noise predictions
 - Deliver ANOPP Level 25 with interfaces for GEN 1 MDAO
 - Incorporate into the BASS code the capability to simulate broadband noise generated as a result of rotor wake turbulence impinging in the stator



Summary

- $N+1$ and $N+2$ technology paths outlined for Subsonic Fixed Wing noise targets.
- NRA Round 1 progressing with focus on prediction method advancement.
- NRA Round 2 initiating work focused on $N+2$ technology, prediction methods, and validation.
- Excellent partnerships in progress supporting $N+1$ technology targets and providing key data sets.